Space Agriculture: Role of NASA's Kennedy Space Center

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NASA's John F. Kennedy Space Center

Kennedy Space Center, Florida

International Congress on Controlled Environment Agriculture
Panama City, Panama 20-22 May, 2015

Biomass Production Chamber

LED Technology

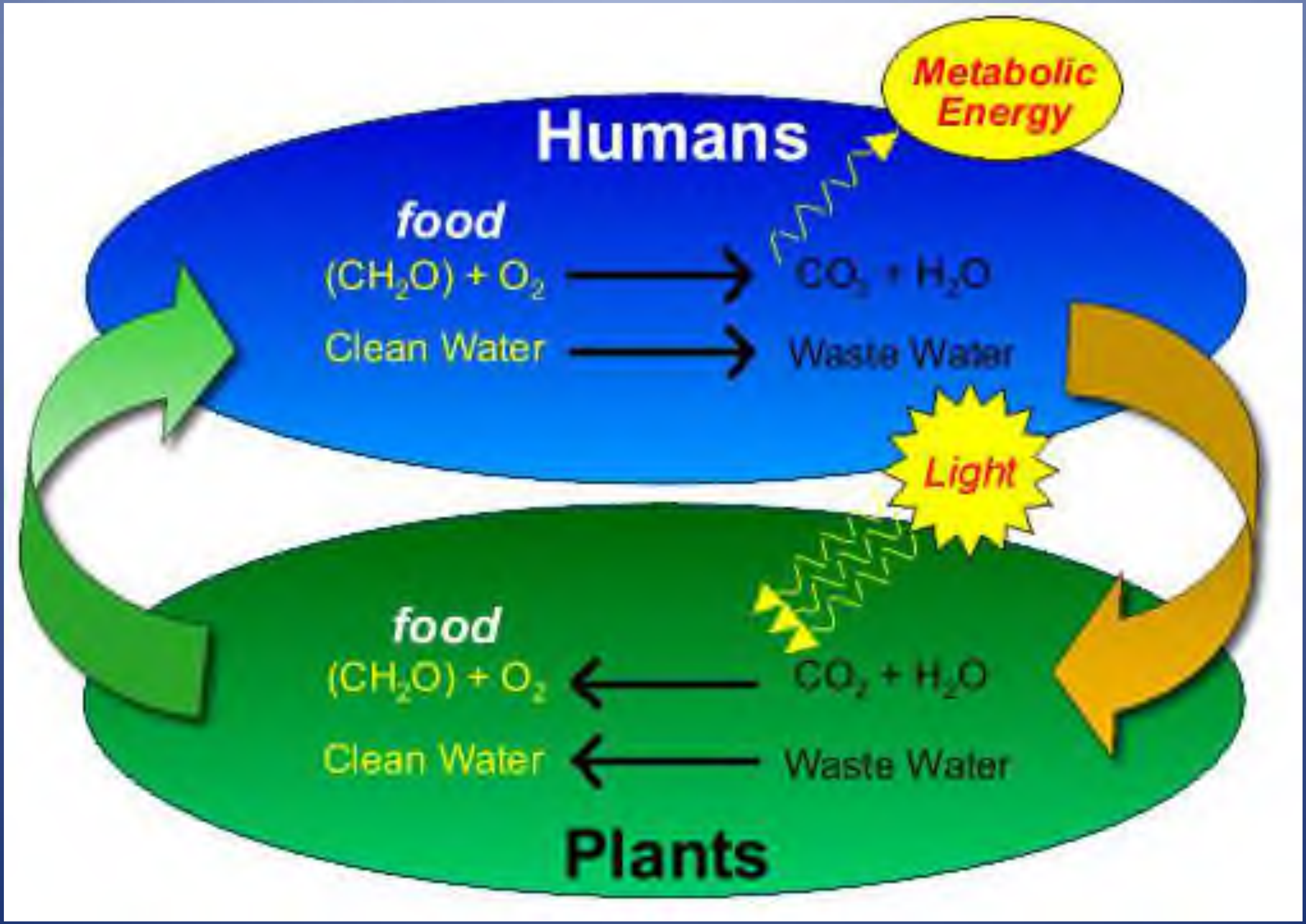
Space Flight Results

Future Developments

Hanger L: Kennedy Space Center, FL

Motts Trading Card, 1950

Bioregenerative Life Support



Human Life Support Requirements for Long Duration Space Missions

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%

TOTAL 31.0 kg

Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)

TOTAL 31.0 kg

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

Biomass Production Chamber (BPC)
Breadboard Scale Ground Testing

Cylindrical chamber (7.5 M x 3.7 M) with internal volume of ~113 m^3.

Four crop growing areas with ~ 5 M^2 growing area (20 M^2 total).

Recycling of water between NDS and HCS.

Leakage of ~ 5-10% per day allowed tracking of CO_2, water, and VOC usage/accumulation.

Four Vertically Stacked Shelves

(5 m^2 each)

View Looking Down (Soybeans)

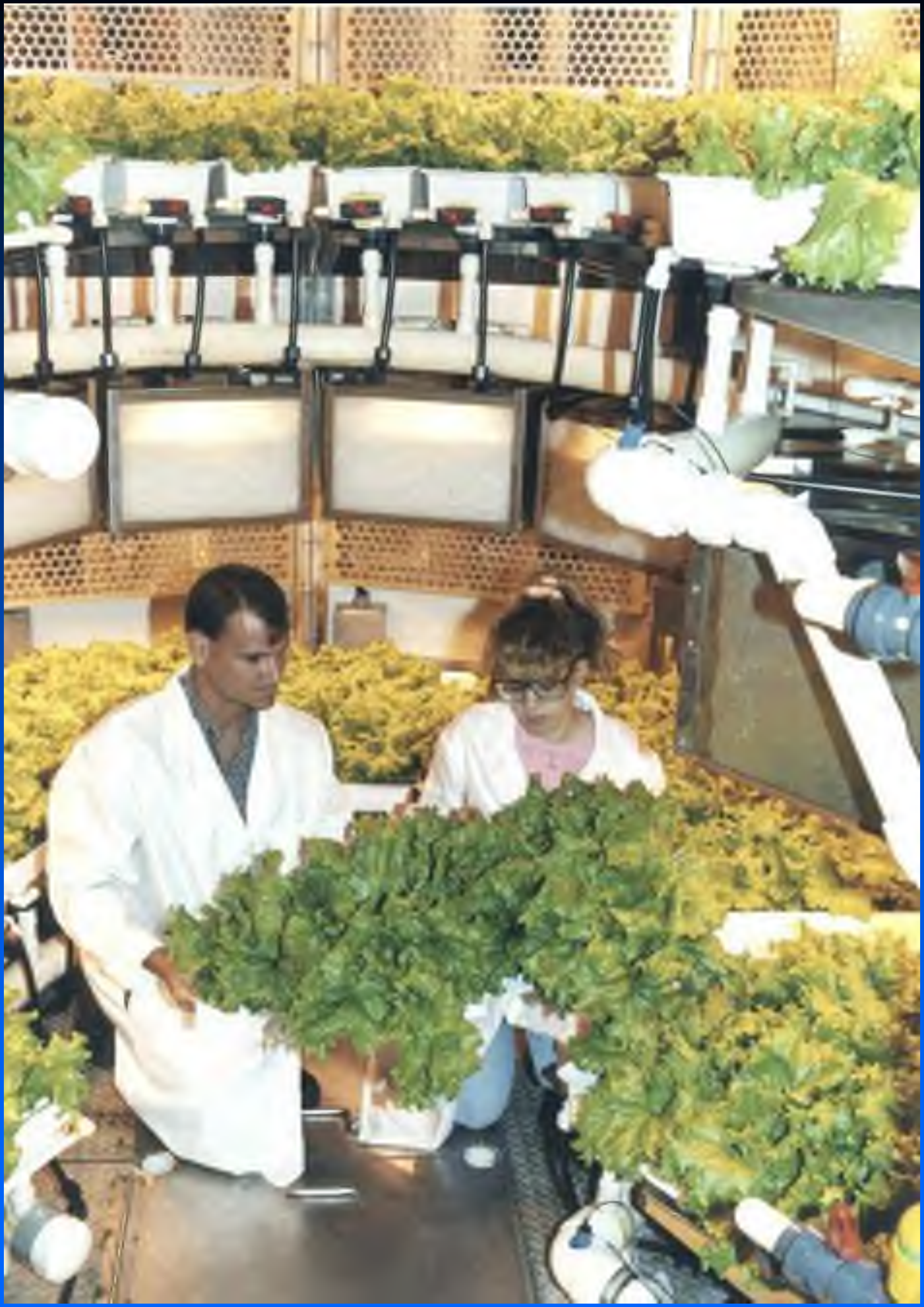
View Looking Up (Wheat)

Lettuce

(Lactuca sativa)
cv. Waldmann's Green

Typical Growth Cycle
28 days

Exceeded all commercial yield models



Tomato

(Lycopersicon esculentum)

cv. Riemann Philipp

Typical Growth Cycle
90-100 days
Achieved over 50% harvest index on dry mass basis

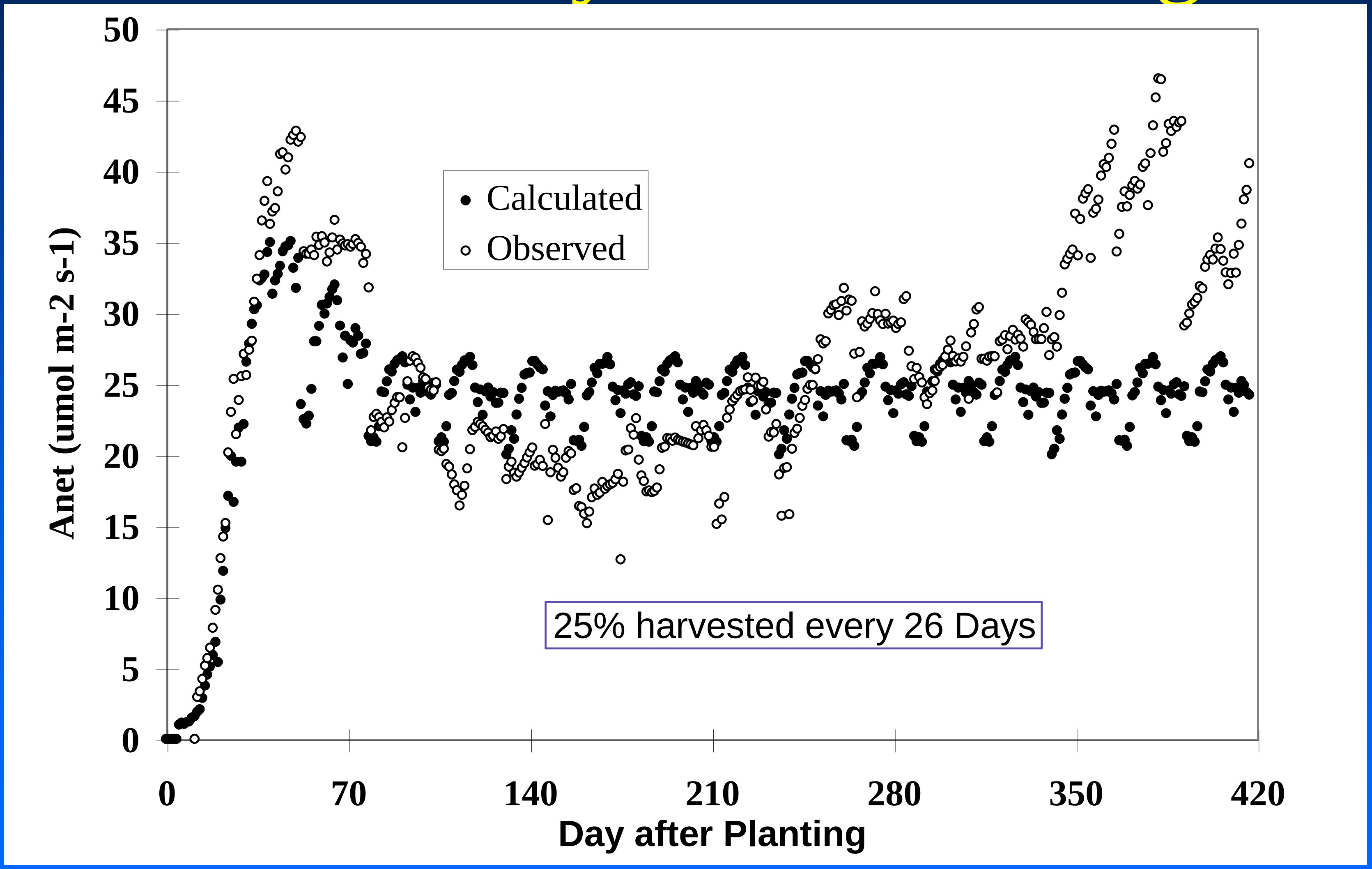
Potato

(Solanum tuberosum)

cvs. Norland and Denali

Typical Growing Cycle
90 – 105 days
2X world record field yields in
2/3 the time

Sustainable potato production over 418 days: Gas exchange



Summary of the life support capabilities of potatoes cv. Norland grown in staggered production cycle for 418 days in Biomass Production Chamber at Kennedy Space Center.

	BWP941 Total	Total Normalized	[Z]Human Needs	Area for Human
Water[y]	13,552 L	3.2 $L\ m^{-2}\ d^{-1}$	19.0 $L\ d^{-1}$	5.9 m^2
CO_2[x]	173 kg	41.4 $g\ m^{-2}\ d^{-1}$	1.0 $kg\ d^{-1}$	24.2 m^2
O_2[w]	126 kg	32.5 $g\ m^{-2}\ d^{-1}$	0.83 $kg\ d^{-1}$	24.2 m^2
Food[v]	61 kg	14.5 $g\ m^{-2}\ d^{-1}$	0.62 $kg\ d^{-1}$	42.8 m^2

[z]Source: NASA SPP 30262 Space Station ECLSS Architectural Control.
[Y]Water need excludes laundry/dishwashing requirement.
[x]CO_2 value is the amount assimilated by photosynthetic tissues.
[w] O_2 value is derived from CO_2 and assumes a 1.00 conversion efficiency.
[v] Food values assume that potato tubers are 17% dry matter.

Crop Species Tested:

- Biomass Production Chamber (BPC)
  - Wheat (*Triticum aestivum*)
  - Soybean (*Glycine max*)
  - Lettuce (*Lactuca sativa*)
  - Potato (*Solanum tuberosum*)
  - Tomato (*Lycopersicon esculentum*)
  - Radish (*Raphanus sativus*)

- Small growth chambers:
  - Same as BPC
  - Sweetpotato (*Ipomea batatas*)
  - Peanut (*Arachis hypogaea*)
  - Beet (*Beta vulgaris*)
  - Spinach (*Spinacea oleracea*)
  - Bean (*Phaseolus vulgaris*)
  - Rice (*Oryza sativa*)
  - Strawberry (*Fragaria ananassa*
  - Pepper (*Capsicum annuum*)
  - Green Onion (*Allium fistulosum*)
  - Carrot (*Daucus carota*)

ISS004E6334

Biomass Production System (BPS)
Small Scale Microgravity Testing

Rectangular chamber (16.5 cm x 14.7 cm x 18.8 cm) with internal volume of ~ .0045 m^3.

Four Plant Growth Chambers (PGC's) with ~0.025 M^2 growing area (0.1 M^2 total).

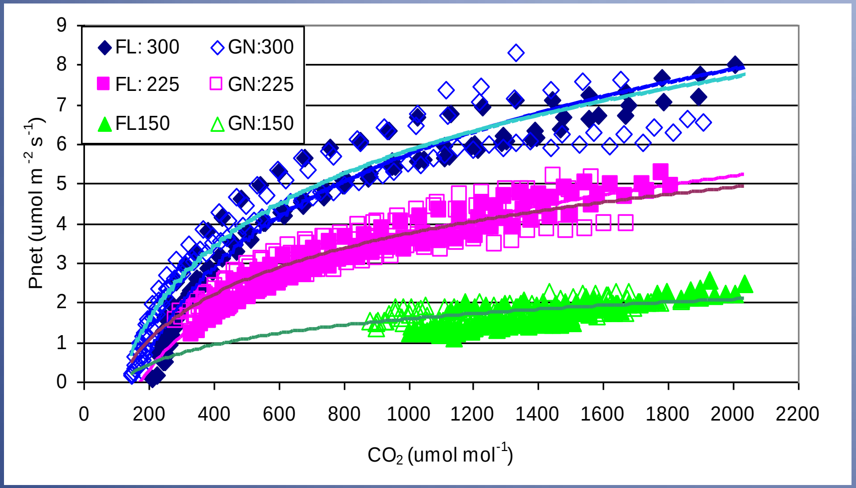
Recycling of water between NDS and HCS.

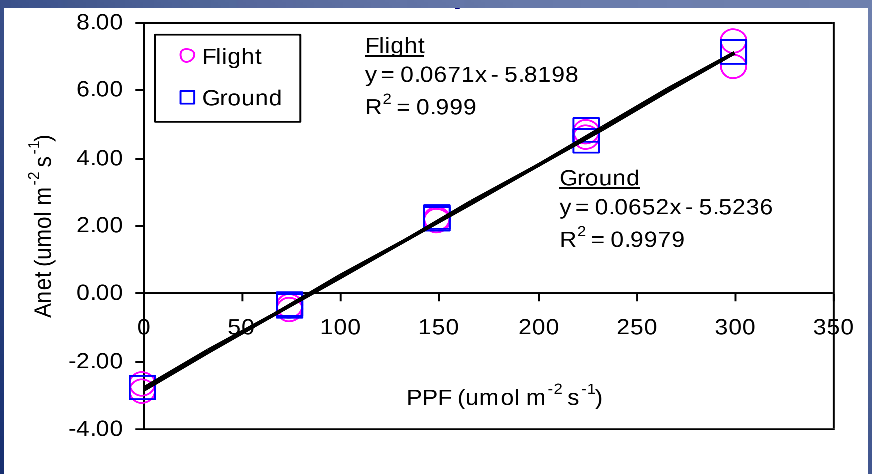
Leakage of ~ 20% per day allowed tracking of CO_2, water, and VOC usage/accumulation.


NASA
STOP

ISS004E10128

Summary of CO2 Exchange Parameters





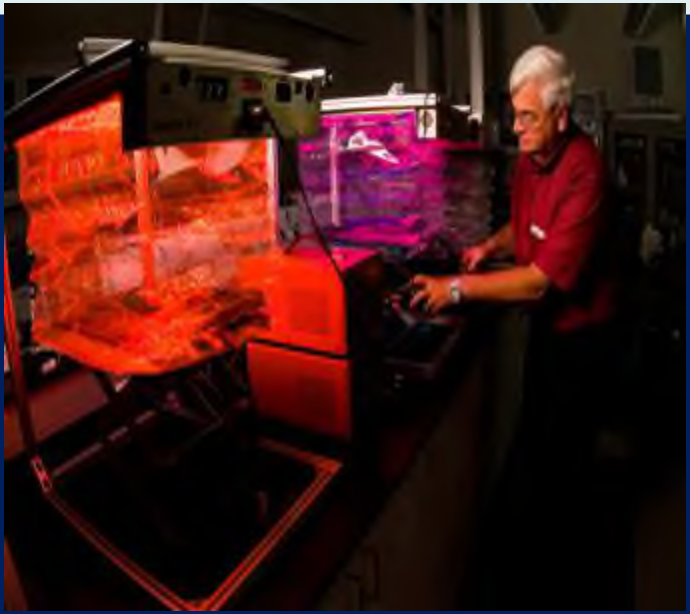
Apogee Wheat 20 DAP	Flight (N=4)	Ground (N=4)	Sig.
Anet stand (μmol m^{-2} s^{-1}) @300 μmol m-2 s-1 PPF	7.8	7.7	n.s
CO_2 comp (μmol mol^{-1}) @ 300 μmol m-2 s-1 PPF	112	105	n.s
PPF comp. (μmol m^{-2} s^{-1}) @ 1200-1600 μmol mol CO_2^{-1}	87	85	n.s
QE (μmol PPF μmol CO_2^{-1}) @ 1200-1800 μmol mol CO_2^{-1}	14.9	15.3	n.s

Data derived from draw downs conducted at FD 9(PGC2); 17 (PGC1); 48 (PGC3); and 69 (PGC1) for both flight and ground control (n=4). Data from 300(*280*), 225(*215*) and 150 (*123*) umol m^{-2} s^{-1} PPF is shown. Logarithmic curve fit used.

Supported by NASA OBPR FBP NRA 96-OLMSA-01 (NCC10-027)

Plant Chambers to Grow Plants in Space

NASA funding supporting LED as lighting source for plant growth


- NASA funded research in LED lighting sources to reduce energy and resupply costs for bioregenerable life support systems for long duration space missions (1986-date).
- NASA funding led to first North American patent for use of LEDs to growth plants (1990).
- NASA incorporated LEDS into flight hardware (1994)
- NASA funding continues supporting LED innovation for plants growth.

LED Studies

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision

Some NASA Related References:

Bula et al. 1991. HortSci 26:203-205.

Barta et al. 1992. Adv. Space Res. 12(5):141-149.

Tennessen et al. 1994. Photosyn. Res. 39:85-92.

Goins et al. 1997. J. Exp. Botany 48:1407-1413.

Kim et al. 2004. Ann. Bot. 94:691-697.

LED's are now being used at commercial level.

Courtesy Caliper Biotherapeutics, Bryan, Texas

Solar Collector / Fiber Optics For Plant Lighting

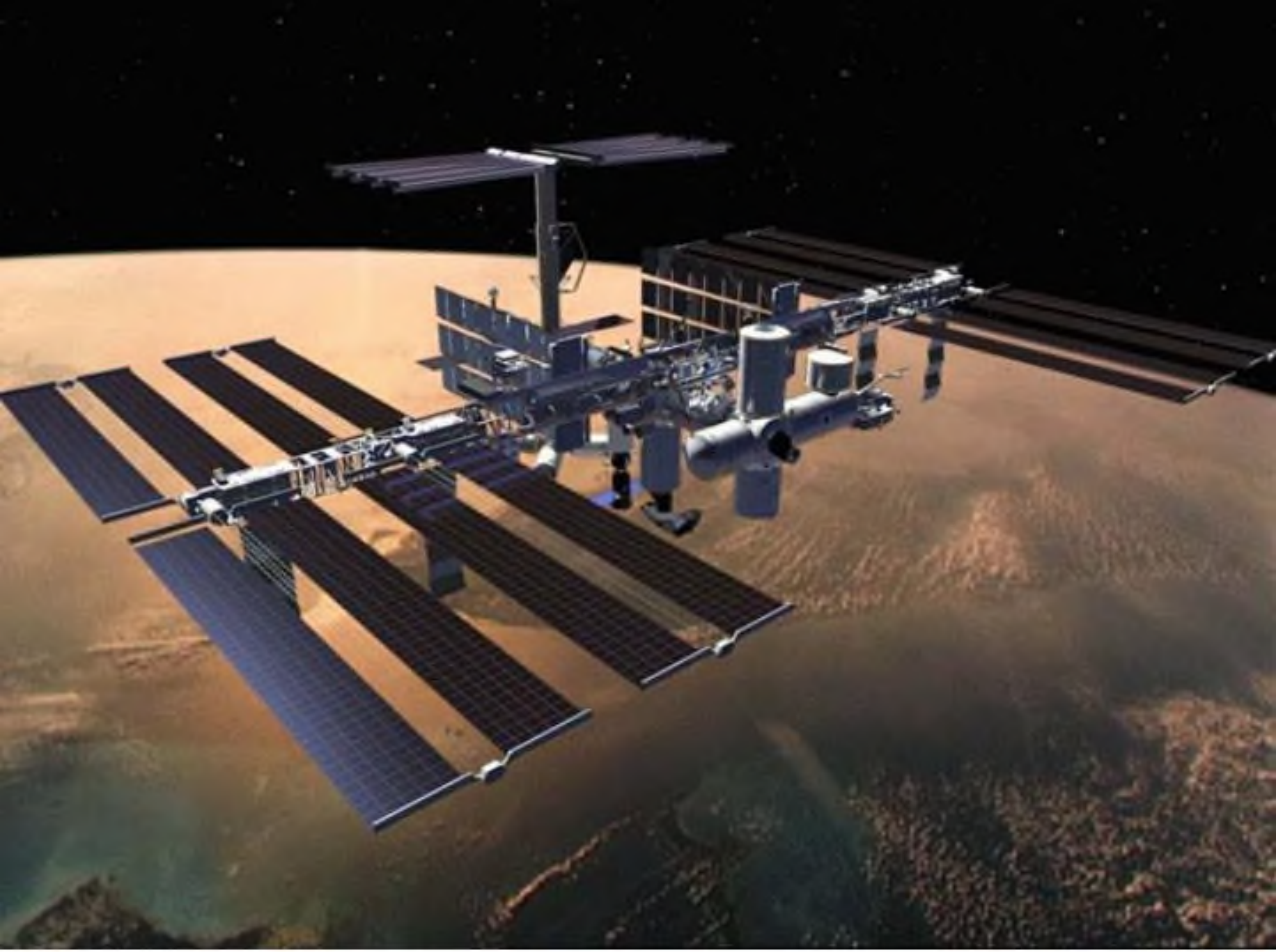
2 m^2 of collectors on solar tracking drive (SLSL Bldg, NASA KSC)

Up to 400 W light delivered to chamber (40-50% of incident light)
Takashi Nakamura, Physical Sciences Inc.

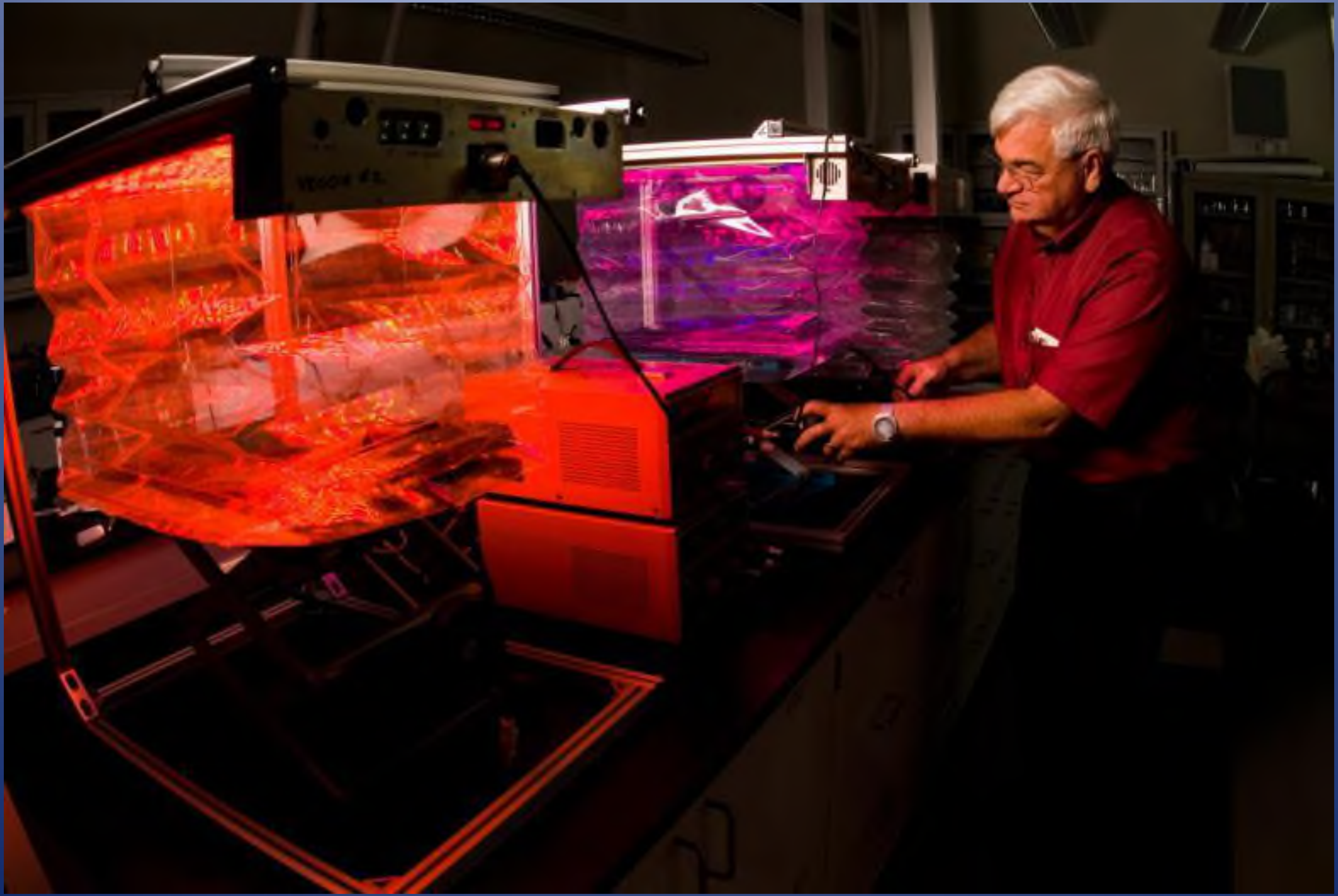
Nakamura et al. 2010. Habitation

Testing of plant production systems for long-duration Missions in Habitat Demonstration Unit (HDU)

LEDs were integrated into a plant atrium in HDU (2011)



Deployable Plant Chambers for Salad Crop Production on ISS: VEGGIE

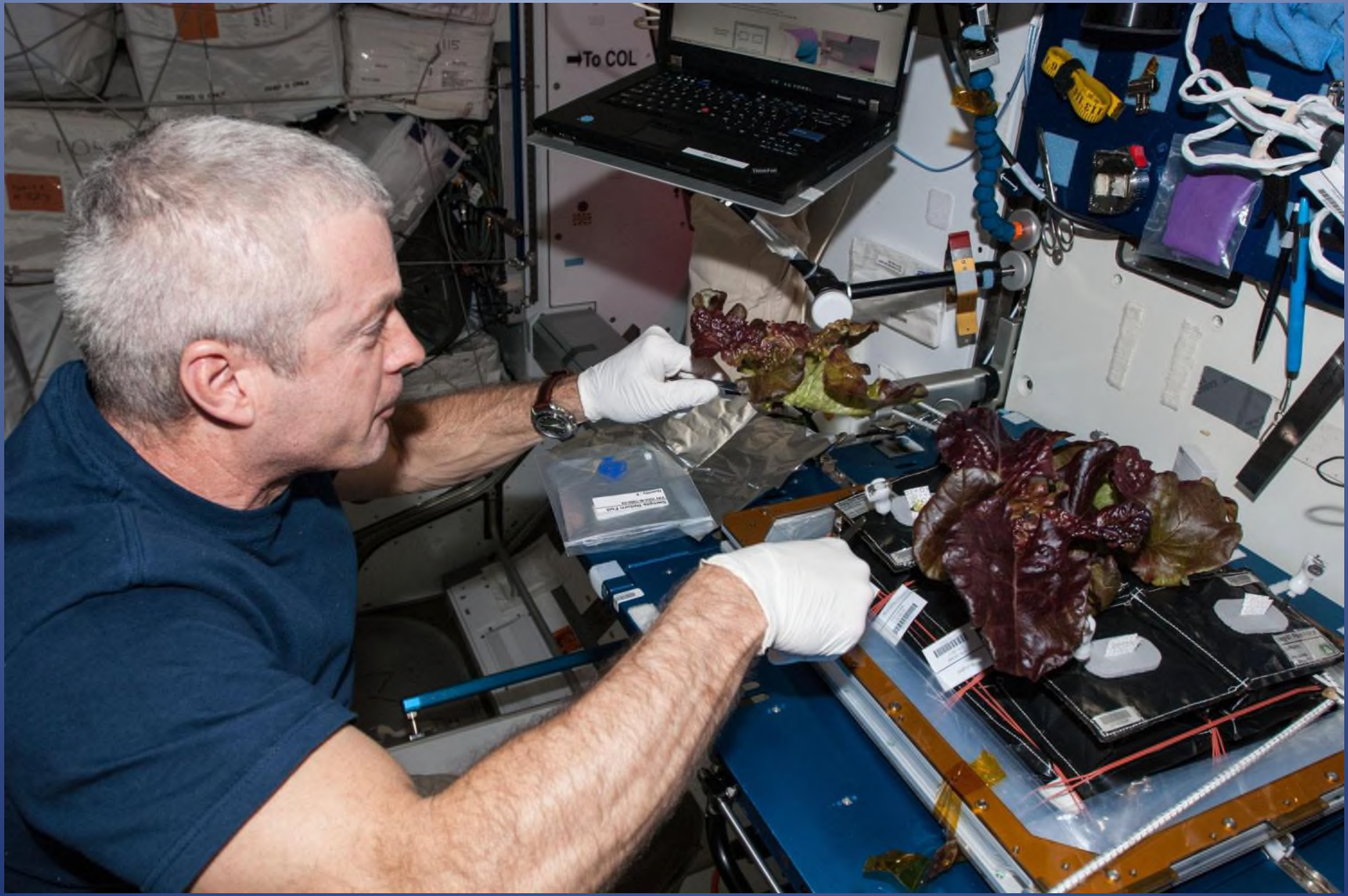


Rooting "pillow's" developed to support salad crop growth in VEGGIE

VEGGIE Plant Chamber is currently on International Space Station

Astronaut Steve Swanson inspects VEGGIE

Lettuce is harvested from VEGGIE



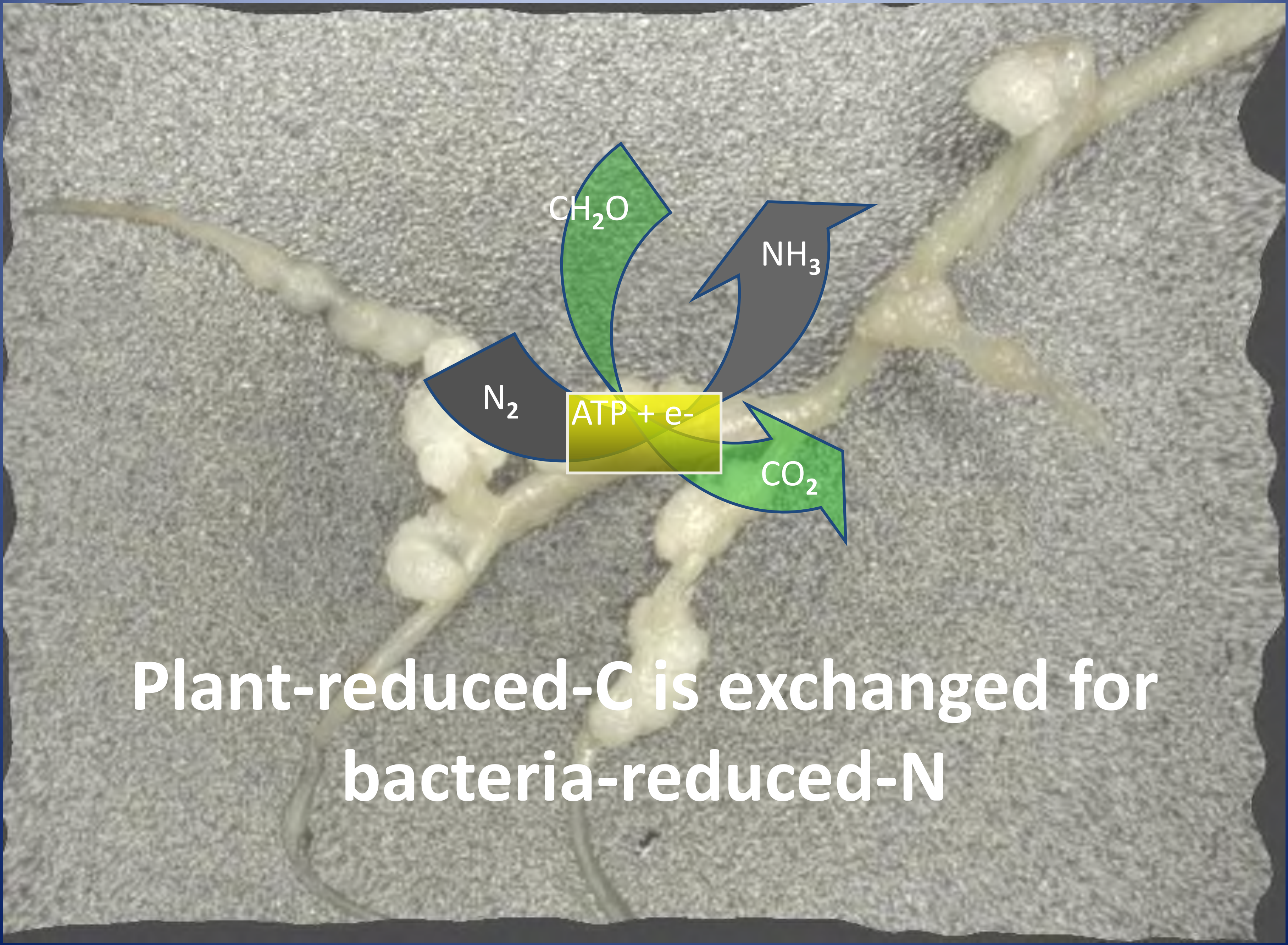
Astronaut Steve Swanson


STS-135
SyNRGE


Medicago tr ula
500.00µm

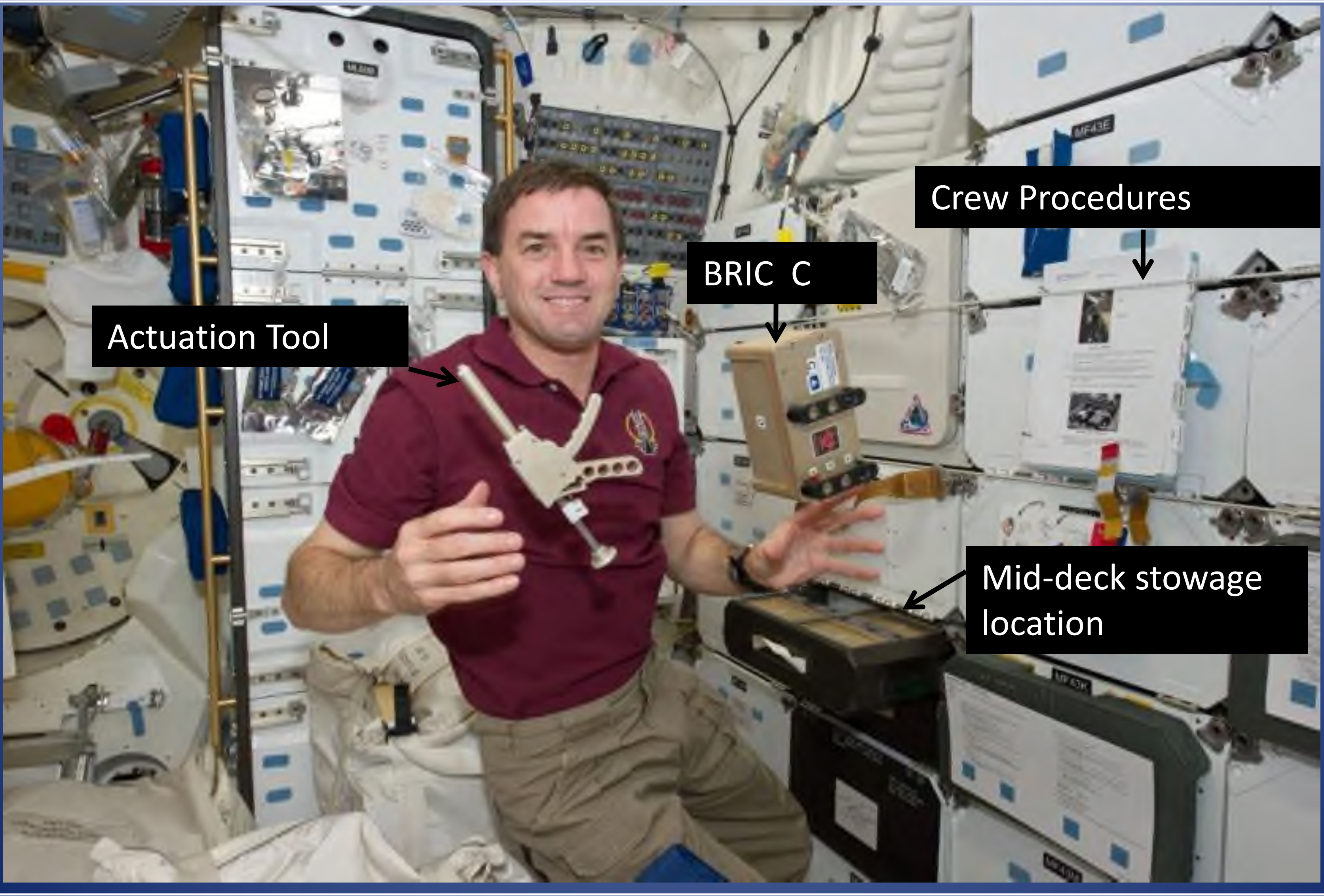

Sinorhizobium meliloti


500.00µm



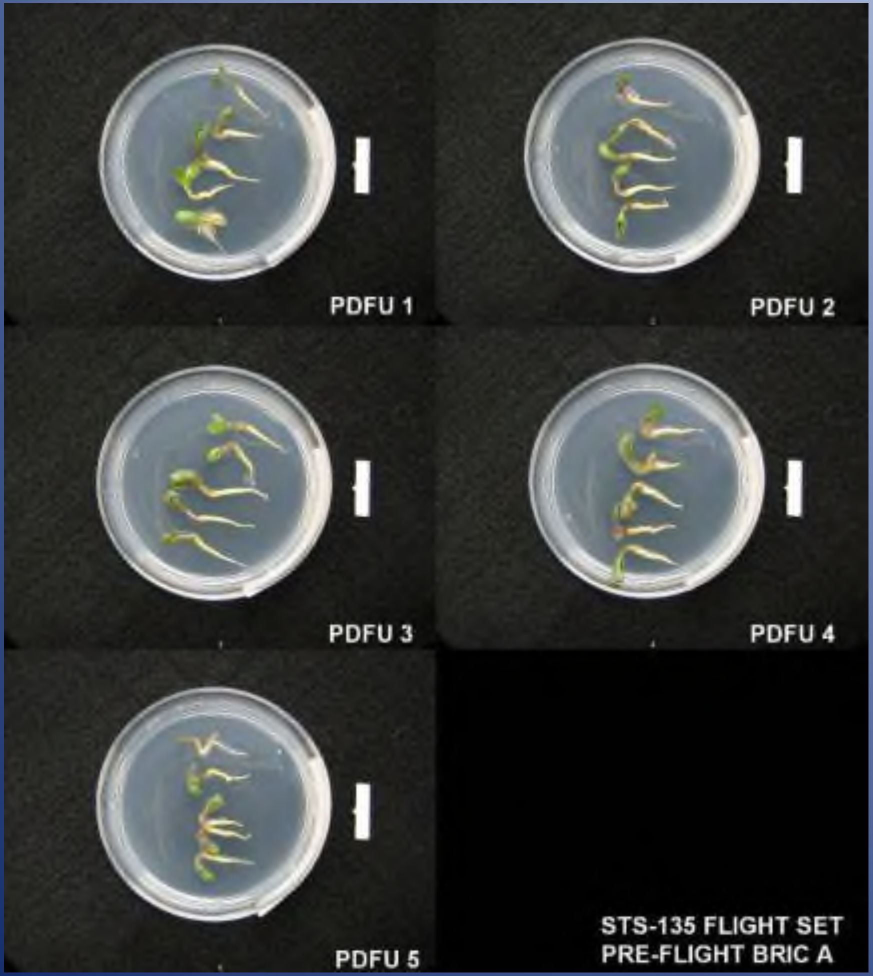
Plant-reduced-C is exchanged for bacteria-reduced-N

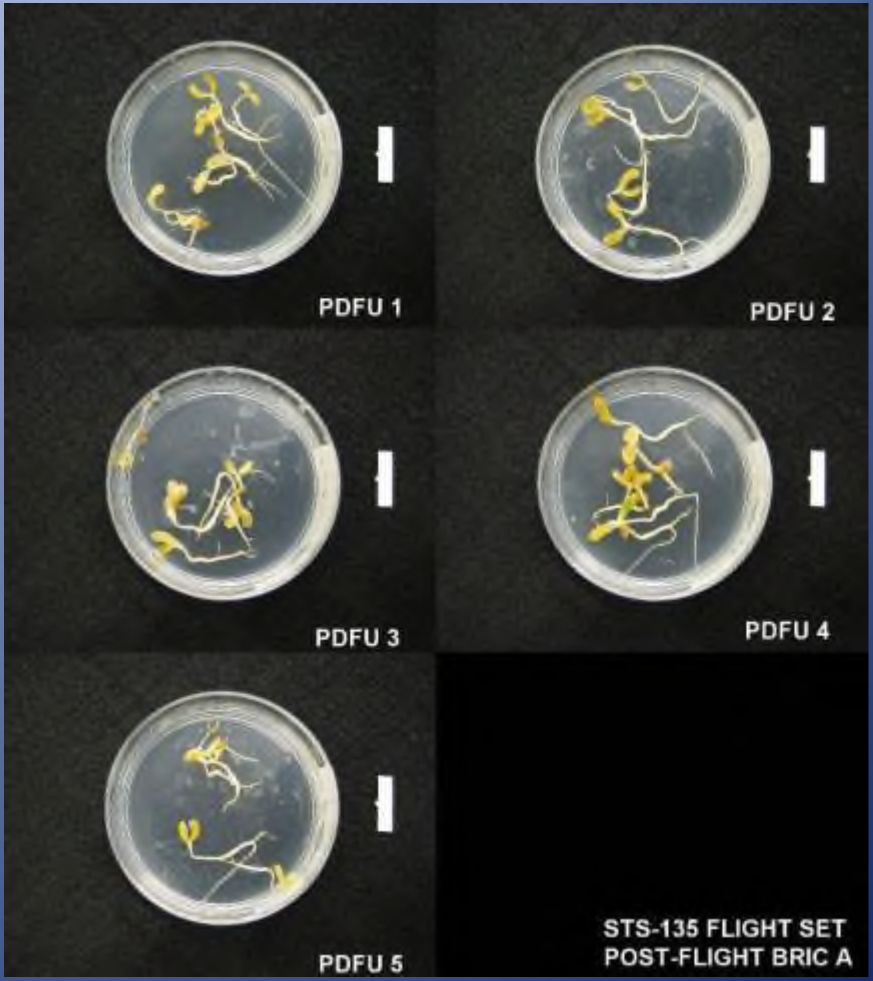
Symbiotic Nodulation in a Reduced Gravity Environment (SyNRGE)



Payload Specialist Rex Wilheim in Space shuttle middeck with BRIC-SyNRGE canister C and activation tool during RNALater Fixation process.

Symbiotic Nodulation in a Reduced Gravity Environment (SyNRGE)





Samples fixed in RNALater

Sustainable, bioregenerative life support systems are critical for survival on long duration space missions.

As we develop tools and knowledge to sustain humans in space, we increase our ability to sustain life on Earth.

Thanks to the team at Kennedy Space Center, Florida

Thank you to organizers, sponsors and participants of the International Congress on Controlled Environment Agriculture